September 1976

U S D A FOREST SERVICE
RESEARCH NOTE RM-324

FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Production of Engelmann Spruce Seed, Fraser Experimental Forest, Colorado: A 5-Year Progress Report

Robert R. Alexander and Daniel L. Noble[1]

Good to heavy seed crops were produced on the Fraser Experimental Forest in Colorado in 4 out of 5 years, with some locations occasionally producing a bumper crop. There was considerable variability in seed crops, however; not all locations produced good crops every good seed year. A tentative relationship was established between 5-year periodic annual seed production, and basal area and average percent live crown of dominant and codominant spruce. Considerably more seedfall data are needed, however, to permit predictions of the frequency of good seed crops and the relationship of average annual quantity of seed produced to stand parameters.

Keywords: *Picea engelmannii*, silvicultural systems, forest seed production.

Prompt establishment of new stands of Engelmann spruce (*Picea engelmannii* Parry) following timber harvest is a major objective in the management of spruce-fir forests in Colorado (Alexander 1974). Good seedbed preparation and favorable environmental conditions are necessary requirements for natural reproduction, but they are of little value without an adequate seed supply. Infrequent good seed crops could restrict the potential for natural regeneration success, and require the use of silvicultural systems that provide a seed supply over long periods of time.

Past studies of Engelmann spruce in the central and southern Rocky Mountains have indicated that intervals between years of good to heavy seed production are sporadic (Alexander 1969, Jones 1967, Ronco and Noble 1971). Knowledge of the frequency of seed crops and the relationship of seed production to stand, tree, and crown characteristics is essential to management of spruce-fir forests with natural reproduction.

A long-term investigation of spruce seed production in high-elevation forests in central Colorado was started in 1968; plots were established by 1970. This Note is a progress report on seed production for the years 1970 through 1974.

[1]*Principal Silviculturist and Associate Plant Ecologist, Rocky Mountain Forest and Range Experiment Station, with central headquarters maintained at Fort Collins in cooperation with Colorado State University.*

Study Areas

A total of 13 permanent square sample plots, 2 chains on a side, were established on the Fraser Experimental Forest. Plots ranged from 9,120 feet to 11,400 feet in elevation, on a variety of slopes and aspects. Ages of dominants averaged from 192 to 292 years. All stands were dominated by Engelmann spruce. Stand characteristics of each location are shown in table 1.

Methods

Seed Production

Seed production was estimated from seeds collected in ten 1-ft² wire seed traps randomly located within each plot. Seed trap contents were collected one or more times each fall beginning in late September, weather conditions permitting, and again the follow-

Table 1.--Stand characteristics, per-acre basis, for dominant and codominant spruce, and total trees

Plot No.	Trees Spruce	Trees Total	Basal area Spruce	Basal area Total	Average diameter Spruce	Average diameter Total	Average height Spruce	Average height Total
	Number		*Square feet*		*Inches*		*Feet*	
1	65	320	84	150	15.4	9.3	78.5	49.5
2	55	250	100	174	1812	11.3	88.0	58.5
3	88	220	133	190	16.7	12.6	60.0	47.0
4	103	323	196	307	18.7	13.2	80.0	59.0
5	95	525	91	255	13.2	9.4	66.0	50.0
6	63	345	101	194	17.2	10.2	85.0	55.0
7	65	365	106	204	17.3	10.1	87.0	52.0
8	65	288	126	213	18.8	11.7	94.0	59.0
9	90	278	102	180	14.4	10.9	84.0	63.0
10	43	283	58	142	15.8	9.6	86.0	54.0
11	35	213	69	138	19.0	10.9	99.0	56.0
12	63	293	77	179	15.0	10.6	79.0	57.0
13	73	203	142	198	18.9	13.4	97.0	68.0

ing spring. All seeds were tested for soundness and recorded as (1) filled or (2) partially filled or empty. Estimates of total quantities of seed produced are based on counts of filled seed only.

Differences in seedfall for locations and years were tested by analysis of variance, with number of filled seeds per trap as the dependent variable. Because of variability in data, seed counts were transformed to $\sqrt{X + 3/8}$.

The following general—and admittedly arbitrary—categories were established to rate seed crops:

Filled seeds (No./acre)	**Seed crop rating**
<10,000	Failure
10,000 - 50,000	Poor
50,000 - 100,000	Fair
100,000 - 250,000	Good
250,000 - 500,000	Heavy
>500,000	Bumper

Stand, Tree, and Crown Characteristics

Stand inventory information was collected as a basis for relating seed production to some measure of stand density, and/or tree and crown characteristics. Information obtained for individual trees on the plots included:

1. Diameter at breast height to the nearest 0.1 inch (trees 3.6 inches d.b.h. and larger).
2. Total height to the nearest 0.5 foot.
3. Crown class.
4. Species.
5. Average length of live crown to the nearest 0.5 foot (average of four sides).
6. Average width of live crown to nearest 0.1 foot (average of two measurements).

Ages of six to eight dominant spruces were measured for determination of site index (Alexander 1967).

The average annual seed production for each location was plotted against individual and combinations of stand, tree, and crown measures. A computer program was then used to select the independent variables best correlated with seed production. Parameters based only on dominant and codominant spruces were used because numerous studies have shown that coniferous species of these crown classes produce three-fourths or more of the seedfall (Fowells and Schubert 1956, Franklin 1968, Haig and others 1941).

Results and Discussion

Seed Production

Seed was produced in larger quantities and at more frequent intervals (table 2) than previous studies

Table 2.--Production of filled seeds per acre, and percent of total seedfall that was filled

Plot No.	1970 Crop[1] Filled seeds	1970 Crop[1] Proportion of total seedfall	1971 Crop Filled seeds	1971 Crop Proportion of total seedfall	1972 Crop Filled seeds	1972 Crop Proportion of total seedfall	1973 Crop[1] Filled seeds	1973 Crop[1] Proportion of total seedfall	1974 Crop Filled seeds	1974 Crop Proportion of total seedfall	5-year average Filled seeds
	Thous.	*Percent*	*Thous.*	*Percent*	*Thous.*	*Percent*	*Thous.*	*Percent*	*Thous.*	*Percent*	*Thous.*
1	148	43	44	17	131	24	13	15	209	48	109
2	680	50	107	26	231	26	17	13	340	52	275
3	531	47	200	21	366	24	52	15	109	21	252
4	558	36	152	31	436	32	4	1	362	33	302
5	544	47	96	23	292	28	17	10	422	33	274
6	292	42	161	21	266	27	13	13	436	43	233
7	218	36	170	23	179	24	30	25	274	33	174
8	366	44	192	30	431	32	35	25	222	40	249
9	362	40	335	23	357	24	9	15	244	38	261
10	104	33	148	24	170	32	9	10	122	36	111
11	83	29	252	38	57	18	9	6	109	37	102
12	401	48	61	14	270	32	17	13	135	38	177
13	161	30	754	25	470	18	22	11	540	47	389
Average	342	42	206	32	281	26	19	12	271	38	

[1]Seeds were not collected in fall because of weather conditions.

indicated were likely (Alexander 1969). In general, good to heavy crops were produced 4 out of the 5 years of observation, with some locations producing one or more bumper crops. In the other year, seed crops were generally rated poor to failure.

Seed crops varied considerably by years and locations. Not all locations produced good to heavy crops every good year. Statistical analyses revealed that differences between locations and years, and the locations x years interaction, were all highly significant.

The amount of filled seed produced was related to total seedfall only in a general way. While there was a tendency for the percentage of filled seed to increase as total seedfall increased, no statistical relationship could be established for these data that would account for more than 60 percent of the variability. Another significant finding of this study is that, despite relatively high seed production in 4 years, only about 25 to 40 percent of the total seed collected was filled in those years.

The time of seedfall was also variable between locations within any year and between years at any location. The percentage of total filled seeds collected, by dates, is shown in table 3 for the years when weather conditions permitted collections in both the fall and the following spring. In 1971, one-third to two-thirds of the total filled seeds produced were released by the end of September, while in 1972, the percentage of seeds released by the end of September varied from 7 to 60. By the second week of October 1972, however, 35 to 70 percent of the seeds had been dispersed. In 1974, only nominal amounts of seed were released at most locations by the third week of September, but 25 to 60 percent had been released by the first week in October.

Relation of Seed Production to Stand and Tree Characteristics

Regression analyses of 21 seed production and stand inventory variables resulted in the following equation:

$$\log Y = 9.9814 - 0.0302\, X_1 + 0.9162 \log X_2,\ R^2 = 0.76$$

where

Y = annual average production of sound spruce seeds per acre.

X_1 = average percent of live crown of dominant and codominant spruces.

X_2 = basal area of dominant and codominant spruces per acre.

The equation accounts for about 76 percent of the total variation in the annual average seed production for the 5-year period. The addition of other variables did not significantly improve the precision of the estimate.

The annual average seed production was used as the dependent variable because there was no way to account for annual variation. Furthermore, the independent variables did not change from year to year.

The equation is not intended for predicting average annual seed production; 5 years of seedfall data are insufficient for this purpose. Furthermore, more seed was produced in the period than was expected from past experience. The form of the equations is likely to remain the same, but the coefficients may change with more data.

Table 3.--Percent of total filled seeds released by collection dates (seeds were not collected in fall for 1970 and 1973 crops because of weather conditions)

Plot No.	1971 Crop		1972 Crop			1974 Crop		
	Sept. 27-28	June 6-21	Sept. 26-27	Oct. 10-11	June 18-July 3	Sept. 15-19	Oct. 2-3	June 24-July 10
1	40	60	60	6	34	12	41	46
2	39	61	43	28	29	9	31	60
3	65	35	10	32	58	16	12	72
4	63	37	9	48	43	0	26	74
5	54	46	23	22	55	0	29	71
6	48	52	23	22	55	00	45	55
7	44	56	34	27	39	3	40	57
8	32	68	38	22	40	16	21	63
9	42	58	42	20	38	4	39	57
10	47	53	41	28	31	25	36	39
11	38	62	23	23	54	20	32	48
12	64	36	7	29	64	16	22	62
13	68	32	42	19	39	29	32	39

Management Implications

Dispersal and survival data from past studies indicate that enough viable seeds were produced in 4 out of 5 years in the current study to adequately restock all aspects under a selection or shelterwood cutting alternative, providing seedbed and environmental conditions are favorable. Enough seeds are produced during the 5-year period to adequately regenerate all clearcut openings, except south aspects, if the openings were kept small enough (3- to 5-acre patches or strips no wider than 400 feet) to be within effective seed dispersal distances, and seedbed and environmental conditions were favorable (Alexander 1974). Clearcutting on south slopes is not likely to result in successful natural spruce regeneration regardless of the quantity of seed available, even with good seedbeds, because of unfavorable environmental conditions.[2]

In some years seed crops will be total failures, and even in years of good overall seed production, not all locations will produce good to heavy crops.

In stands to be cut under a selection or shelterwood system, full- and long-crowned dominants and codominants should be retained as leave trees. These trees not only produce the most seed, but are also the most windfirm—an important consideration in partial cutting of high-elevation spruce forests. If trees are marked during a good seed year, it is possible to select the dominants and codominants with the largest number of cones. In years when seep crops are poor, old cones on the ground usually indicate which trees are likely to be the best seed producers.

Guidelines developed for partial cutting in old-growth spruce forests (Alexander 1973) require more leave trees because of wind risk than are needed for seed production. Furthermore, windfall susceptibility of trees and stands is more important than spacing of trees for seed production. If the leave trees blow down, there is no seed source.

In managed stands, the number of trees left at the time of the seed cut under a shelterwood system will vary from 15 to 35 dominants and codominants per acre, depending upon the number of entries in the system, growing stock level selected and site productivity (Alexander and others 1975). This should be more than an adequate seed source for natural regeneration if seedbeds are properly prepared.

This study will be continued indefinitely to provide more information on (1) the quantity of seed produced and frequency of good to heavy seed crops, and (2) the relationship of filled seed production to stand, tree, and crown parameters. Other investigations will include the effect of cone insects on seed production, and the development of a rating system to estimate seed crops from cone counts.

[2] *Noble, Daniel L., and Robert R. Alexander. Environmental factors affecting the regeneration of Engelmann spruce. (Manuscript in preparation at Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.)*

Literature Cited

Alexander, Robert R.
1967. Site indexes for Engelmann spruce in the central Rocky Mountains. U.S. For. Serv. Res. Pap. RM-32, 7 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Alexander, Robert R.
1969. Seedfall and establishment of Engelmann spruce in clearcut openings: A case history. USDA For. Serv. Res. Pap. RM-53, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Alexander, Robert R.
1973. Partial cutting in old-growth spruce-fir. USDA For. Serv. Res. Pap. RM-110, 16 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Alexander, Robert R.
1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge. USDA For. Serv. Res. Pap. RM-121, 88 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Alexander, Robert R., Wayne D. Shepperd, and Carleton B. Edminster.
1975. Yield tables for managed even-aged stands of spruce-fir in the central Rocky Mountains. USDA For. Serv. Res. Pap. RM-134, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Fowells, H. A., and G. H. Schubert.
1956. Seed crops of forest trees in the pine region of California. U.S. Dep. Agric., Tech. Bull. 1150, 48 p.

Franklin, Jerry F.
1968. Cone production by upper slope conifers. U.S. For. Serv. Res. Pap. PNW-60, 21 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Haig, Irvine T., Kenneth P. Davis, and Robert H. Weidman.
1941. Natural regeneration in the western white pine type. U.S. Dep. Agric., Tech. Bull. 767, 98 p.

Jones, John R.
1967. Regeneration of mixed conifer clearcuttings on the Apache National Forest, Arizona. U.S. For. Serv. Res. Note RM-79, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Ronco, Frank.
1970. Engelmann spruce seed dispersal and seedling establishment in clearcut openings in Colorado—a progress report. USDA For. Serv. Res. Note RM-168, 7 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Ronco, Frank, and Daniel L. Noble.
1971. Engelmann spruce regeneration in clearcut openings not insured by record seed crop. J. For. 69:578-579.

Agriculture—CSU, Fort Collins